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# Overview of the Malawi energy situation and A PESTLE analysis for sustainable development of renewable energy

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ABSTRACT

This paper presents an overview of the Malawi energy situation and the potential of renewable energy resources including solar, wind, biomass, hydro and geothermal. Despite a range of efforts by local and international stakeholders to increase access to modern energy sources in the country, 89 per cent of Malawi's energy is still sourced from traditional biomass mainly fuel wood. Only 8 per cent of the population in Malawi have access to electricity but installed capacity of electricity generation is lower than demand. This leads to load shedding by the electricity supplier; consequently electricity supply in Malawi is unreliable and micro and macroeconomic activities are significantly affected. Solar, non-traditional biomass (crop residues and forest residues not burnt on three stone fireplaces, and biogas), hydro, wind and geothermal are potential energy resources that could enhance Malawi's energy security. However, unreliable financing mechanisms for large scale energy projects; shortage of trained human resource; lack of coordination among local institutions; unclear regulation enforcement; and sometimes political governance impede sustainable delivery of energy projects. The Malawi energy policy targets and drivers are also discussed in the paper. Based on the prevailing energy situation, a PESTLE analysis is provided in this paper outlining a novel thinking for addressing the political (P), economic (E), social (S), technological (T), legal (L), and environmental (E) challenges that constrain the development of renewable energy technologies in Malawi.



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## 1. Introduction

Malawi is a land-locked country located in south eastern Africa and lies between 32.5°E and 35.9°E longitudes; and 9.3°S and 17.1°S latitudes. The country is bordered by Tanzania to the north, Zambia to the west and Mozambique to the south and east. An extract of the country's demography is shown in Table 1.

The country earns over 80 per cent of export earnings from agriculture, which also provides over 85 per cent of employment and contributes about 35 per cent of GDP, second to Services at 46 per cent; manufacturing contributes only 19 per cent of GDP [6]. About 50 per cent of Malawians live below US$2 per person per day [6]. Despite the social growth reported in [7], there is a unanimous consensus in the country that low access to and poor modern energy limit economic development. Therefore, the overall aim of this paper is to review the energy situation facing Malawi in the light of limited access to modern energy services and the need to develop these services making use of renewable energy technologies. The objectives are to present data on the current energy mix for Malawi, to outline the current energy policies for Malawi; to review the renewable energy resources that are available, and to analyse challenges to the development of energy infrastructure along with provision of clear cut options. The paper complements recent works of Gondwe et al. [8], Kaunda [9], Gamula [10] and Tenthani et al. [11]. It is intended that this paper provides a concise reference of energy resources and technology options for Malawi which is difficult to find in one piece as yet. The novel contribution of this work is the PESTLE analysis which has been laid out to envision the long-term supporting mechanisms for renewable energy delivery for Malawi based on political (P), economic (E), social (S), technological (T), legal (L), and environmental (E) criteria. The organisation of the paper is as follows: Section 2 presents the installed capacities of energy technologies; Malawi's energy balance is presented in section 3, and section 4 outlines the Malawi Energy Policy; whilst the potential renewable energy resources, challenges for the energy sector, and the PESTLE analysis for delivery of renewable energy technologies are discussed in sections 5–7 respectively. The conclusion is set out in section 8. The data presented is based on reports from government and public institutions of Malawi, a range of online resources and first-hand information by the involvement of the authors in the Malawi energy sector. Necessary measures were taken to ensure that reference is made to the most recent documents and data; but this may be limited by overdue official reviews for the country.

**Table 1**
Demography extract for Malawi.

| | |
|---|---|
| Total Area | 118, 484 km$^2$ [1] |
| Population | 15.91 million [2] |
| Population growth rate | 2.8 per cent [3] |
| Access to grid electricity | 8 per cent [4] |
| GDP per capita (PPP) | US$800 [5] |

## 2. Installed generation capacities of energy technologies in Malawi

Table 2 shows estimated installed capacities of the energy technologies. Estimates of solar photovoltaic (PV), wind and biogas are based on informal surveys and varying unpublished information due to the lack of a reliable information management system for energy statistics for the country. The whole of the large hydro and 4.35 MW of the small hydro is owned by the Electricity Supply Corporation of Malawi (ESCOM). The fossil-fuel run generators include 750 kW for Likoma Island 300 kW for Chizumulu Island and 1.1 MW standby for Mzuzu (all owned by ESCOM) and excludes diesel-run generators privately owned by institutions and companies. There are 289 privately owned diesel-run generators registered with the Malawi Energy Regulatory Authority. The privately owned diesel-run generators add up to 52 MW which includes 10.2 MW for the Kayerekela uranium mine. The biomass based electricity generators are privately owned by the only sugar producing company, Illovo; and as at 2013 the generators were not feeding into the grid yet. The ethanol is produced from sugarcane molasses (by-product from sugar making at Illovo) by two private companies namely Ethanol Company and Prescane Limited. The PV, biogas and wind systems are mainly standalone household and/or institutional systems in schools, rural healthcare centres, remote offices, and tourist accommodation places.

## 3. Malawi's energy balance

Most recent detailed studies of energy consumption in Malawi were conducted in 2008 but it is unlikely that the energy statistics have changed significantly between 2008 and 2014. The gross energy consumption for Malawi was 156,295 TJ in 2008 [16]. Fig. 1 shows the energy consumption by sectors and Fig. 2 shows the energy consumption by category of sources.

It can be seen from Fig. 1 that households contribute over 80 per cent to the energy demand, whilst Fig. 2 shows that traditional biomass is the major source of energy in Malawi. Overdependence on traditional biomass has resulted in wood demand surpassing sustainable wood supply by more than 3.7 million tonnes per annum [18]. Electricity is supplied by a sole state owned Electricity Supply Corporation of Malawi (ESCOM) which is also the grid operator. Hydropower contributes 99 per cent of grid electricity; 98 per cent of this is generated along the Shire River. The electricity generation capacity is lower than demand: with only 8 per cent of Malawians accessing grid electricity services [6,19], the electricity supplier is still compelled to carryout load-shedding. Petroleum products are exclusively imported, except that the country produces ethanol which is, in one part, intended for blending with petrol in the ratio of 20:80 [13,10] although in practice the blending ratio was 10:90 as at June 2013 [10,15,9]. About 60,000 t of coal is produced every year. Some of the coal is used in local industries such as tobacco processing, and breweries and another proportion is exported to Tanzania. Most of the

**Table 2**
Installed generation capacities of energy technologies for Malawi.

| Technology | Installed Capacity |
|---|---|
| Large-scale hydro | 345.5 MW [12,13] [a] |
| Small-scale hydro | 5.8 MW [12,13,9] |
| Thermal electricity (fossil fuel driven turbines) | 2.15 MW [12,13] |
| Solar PV | > 7000 installations ( ~1 MW) [14] |
| Wind | No reliable data available but < 1 MW |
| Biogas | Around 40 fixed dome (~120 $m^3$ mainly using cow dung; one 12 $m^3$ using human waste) |
| Biomass (sugarcane bagasse) | 18 MW [15] |
| Ethanol | 18 million l per annum [13,9] |

[a] This includes the Kapichira 64 MW which was commissioned in January 2014.

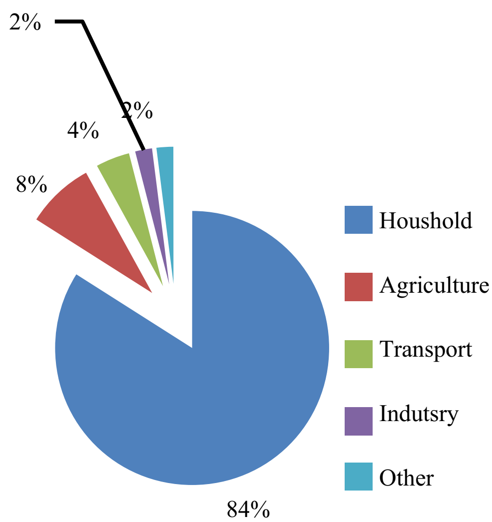


**Fig. 1.** Malawi's energy consumption by sectors in 2008—adapted from [17,16].

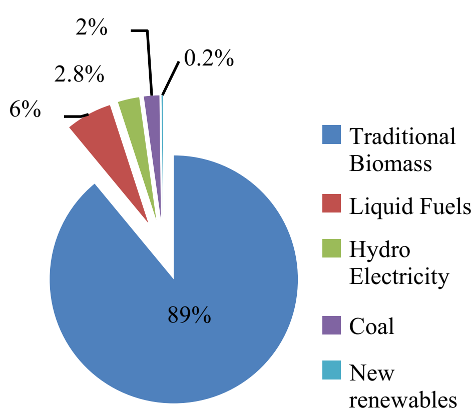


**Fig. 2.** Malawi's energy consumption by source in 2008—adapted from [16].

manufacturing and processing industries in Malawi are located in southern region which is closer to Mozambique from where the industries easily import part of their coal demands. New[2] renewable energy technologies in Malawi include off-grid solar photovoltaic systems, small off-grid wind turbines and fixed-dome biogas systems mainly installed in rural communities. Uranium mining was also started in 2010. Over 670 t of uranium was produced in 2011 [20] but all uranium is exported; there are no nuclear power plants in

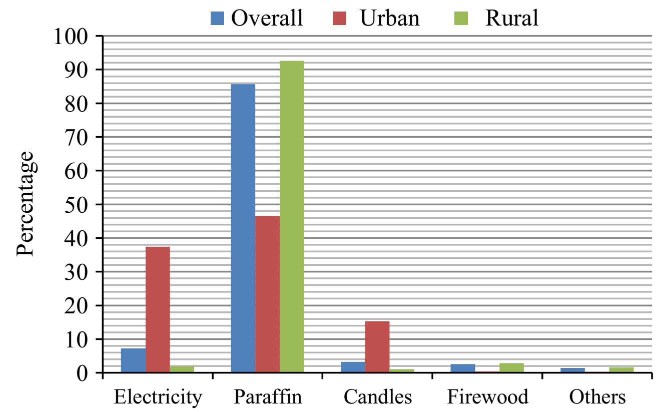


**Fig. 3.** Distribution of energy sources for household lighting for Malawi in 2008—adapted from [3].

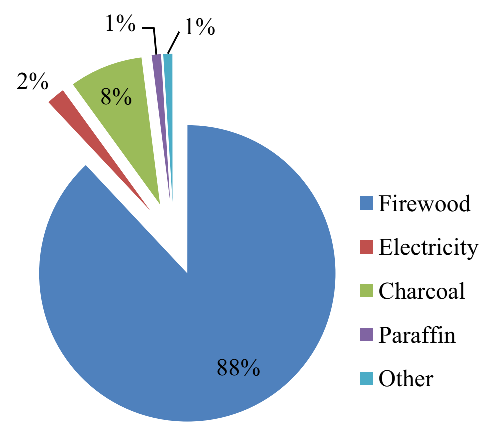


**Fig. 4.** Distribution of energy sources for household cooking for Malawi in 2008—adapted from [3].

Malawi yet. Paraffin and firewood are the major sources of lighting and cooking respectively for households. Figs. 3 and 4 show the distribution of energy sources for lighting and cooking respectively at household level.

Fig. 4 shows that firewood and charcoal are used by 96 per cent of the population in total for cooking. The Malawi energy policy aims to reduce the country's reliance on traditional energy sources by increasing access to modern energy sources. Therefore, the next section outlines the energy policy along with the drivers which have been established to help the country meet the policy targets.

## 4. Malawi's energy policy

Malawi's Energy Policy attributes the energy supply problems and the energy balance presented in the previous sections to three factors as outlined in the Malawi Vision 2020 [21]. These are:

(i) Inadequate, unaffordable, unreliable and inaccessible electricity due to monopolistic structures, under-developed services, poor management, lack of competition and cultural inertia;
(ii) Over dependence on imported and relatively high cost petroleum products; and
(iii) Over dependence on fuel wood largely produced from indigenous forests with aggregate consumption exceeding levels of sustainable fuel wood yields by about 30 per cent.

[2] The term is used to differentiate from large hydro which has been used in Malawi since the 60s.

The Energy Policy aims to address the energy supply problems by:

(i) Improving efficiency and effectiveness of the commercial energy supply industries;
(ii) Improving the security and reliability of energy supply systems;
(iii) Increasing access to affordable and modern energy services; and
(iv) Improving energy sector governance; and mitigating environmental, safety, and health impacts of energy production and utilisation.

The energy-mix targets for Malawi are shown in Fig. 5. The base year is 2000.

In order to achieve the targets shown in Fig. 5, the objectives of Policy are set as follows:

(a) Exploitation of other hydropower sites and developing coal and biomass thermal plants;
(b) Interconnection with neighbouring countries;
(c) Research and Development (R&D) into new fuel-ethanol applications;
(d) Promotion of the use of affordable alternative energy sources for all fuel wood users through capital subsidies, tax breaks, technical and institutional support for market priming activities involving Renewable Energy Technologies Industries; and
(e) Acceleration of rural electrification.

Therefore, a number of reforms have been implemented after the formulation of the energy policy in 2003. These include:

(i) The establishment of the regulation act 2004 which lead to the formation of the Malawi Energy Regulatory Authority (MERA), and energy regulation laws 2008;
(ii) The establishment of the rural electrification fund through the rural electrification act 2004, and rural electrification regulations 2008;
(iii) Permitting private sector to invest in generation, transmission and distribution of electricity through the electricity act 2004, electricity by-laws 2008, and public private partnership arrangement;
(iv) The establishment of the liquid and gas fuels act 2004, and liquid and gas regulations 2008 to regulate the licensing, pricing, taxation, and safety in the production, supply and storage of liquid and gas fuels;

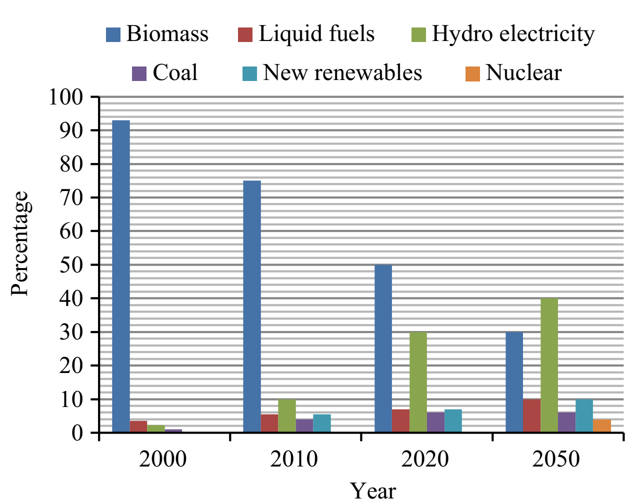


**Fig. 5.** Malawi's energy-mix projections (2000 values are actual)—adapted from [13].

(v) The establishment of the Test and Training Centre for Renewable Energy Technologies (TCRET), though not operational as yet, at Mzuzu University; and
(vi) Removal of duty and surtax on importation of renewable energy technology equipment.

Despite the above reforms, by 2010 the energy balance of Malawi comprised around 89 per cent biomass compared to the target of 75 per cent biomass usage for the same year. Owen et al. [16] projected that Malawi will still source up to 82 per cent of its energy from biomass in 2020 which would be an underperformance based on the targets shown in Fig. 5.

Most recently, in 2012, a feed-in tariff (FIT) policy [22] was introduced for renewable generated electricity to accelerate private sector investment in renewable energy technologies. The tariffs were set as follows:

a. US$0.20 and US$0.10 per kWh for firm and non-firm power respectively generated from solar PV;
b. US$0.13 per kWh for electricity generated from wind;
c. US$0.10 – US$0.13 per kWh and US$0.08-US$0.12 per kWh for firm and non-firm power respectively for electricity generated from small hydro depending on the size;
d. US$0.08 per kWh and US$0.10 per kWh for firm and non-firm power respectively for electricity generated from biomass including biogas; and
e. US$0.105 per kWh for power generated from geothermal.

Given the energy policy, the next section discusses the available potential of renewable energy resources in Malawi; and notable advances in utilisation of the renewable energy resources.

## 5. Renewable energy resources and advances

### 5.1. Solar resource

Average solar irradiation in Malawi on an horizontal surface is 5.8 kWh/m$^2$ per day [13]. Fig. 6 shows typical monthly solar irradiation for Malawi.

Based on the average minimum and the average maximum irradiation shown in Fig. 6, the potential solar energy on a horizontal surface ranges from 1642.5 to 2555 kWh/m$^2$ per annum. It should be noted that on an inclined surface which is the usual way of installing solar energy collectors, the irradiation could be higher than on a horizontal surface by about 2 per cent on average and about 20 per cent in winter months. At 15% module efficiency, the available irradiation can yield over 6000 GWh per annum from less than 2% (18 km$^2$) of the country's land area compared to an electricity consumption of 1900 GWh in 2011 [12]. The potential energy yield could be higher from solar thermal collectors which normally operate at efficiencies ranging between 30 to 60 per cent [24]; thus giving greater prospects for solar thermal applications including concentrated solar power (CSP). Water heating and cooking contribute a significant amount of the electricity demand in the country as evidenced by the load shedding which is usually scheduled at times of cooking and water heating from early mornings to midday and early evenings. Solar thermal applications for water heating and cooking have potential to offset a significant amount of the electricity demand on the grid power system and thus reduce pressure on the grid network which would lead to better electricity services for industry and households. Thermal applications also have potential to reduce demand for fuel wood. Because solar irradiation peaks at around midday, a time when most people in Malawi prepare lunch, solar thermal applications for cooking can coincide with demand.

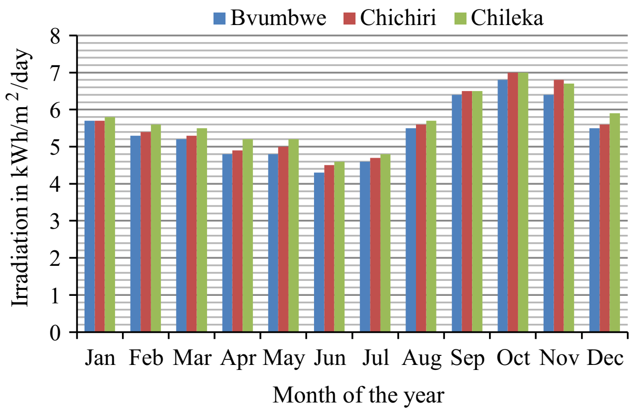


**Fig. 6.** Monthly mean solar irradiation from three weather stations for Malawi-based on 2010 measured data from the Department of Climate Change and Meteorological Services [23].

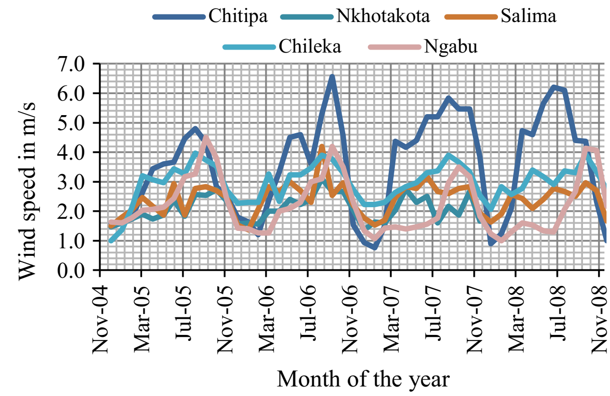


**Fig. 7.** Four years monthly average wind speeds at 2 m height for five selected stations for Malawi—based on measured data from the Department of Climate Change and Meteorological Services.

Solar thermal water heating systems are already in use by a few healthcare centres, mission centres and a few households but require up-scaling and broadening the application to other facilities such as boarding schools where demand for firewood or electricity for cooking and water heating per property is likely to be higher. Advances of solar PV in Malawi include six isolated mini-grid PV systems which were implemented as hybrid systems with wind turbines on a scale of 25 kW each (15 kW from Solar PV) supplying about 150 household each [25], whilst stand-alone PV systems continue to be installed in rural health centres, schools and households since the onset of the Barrier Removal to Renewable Energy Project in Malawi (BaRREM) in 2002 which phased out in 2008. Some charity organisations, for example, World Vision use PV systems for water pumping to supply piped water to rural communities. These efforts can be supplemented with large scale PV systems which can feed into the grid and thus significantly improving the energy security and reducing uncertainties arising from overreliance on the hydropower-generation. The biggest milestone in the application of PV systems in Malawi is the 850 kW grid-connected system at Kamuzu International Airport in Lilongwe which was commissioned in September 2013.

### 5.2. Wind resource

Fig. 7 shows a plot of monthly mean wind speed, at 2 m height, between Jan 2005 and December 2008 for five selected stations; Chitipa from the north, Nkhotakota and Salima from the central, and Chileka and Ngabu from the south of Malawi. It can be seen from Fig. 7 that for the five stations the monthly mean wind speeds are above 2 m/s for a significant period. The wind speeds peak in July until October remaining above 3 m/s. It should be noted that the peaking of the wind speed coincides with a time when rivers' levels and the water table have gone down necessitating water pumping for household water supply and agricultural irrigation. During the same period, atmospheric temperatures are high necessitating space cooling; thus there is high probability of wind energy generation coinciding with demand.

The wind speeds shown in Fig. 7 are viable for mechanical water pumping and for small scale electricity generation probably at hub heights of more than 10 m above the ground due to minimised sheltering effects and reduced effects of terrain roughness at higher heights. But further analysis using, for example, the Weibull distribution and hourly wind speed data would be essential to determine achievable capacity factors for the potential wind energy systems. Comprehensive countrywide wind resource mapping is also required due to the unreliability and uncertainties of wind speed measurement at 2 m height in the majority of the country's weather stations; as of 2013 only 3 out of 22 weather stations took wind measurements at 10 m height [26]. Major developments in the Malawi's wind energy is the work of the Malawi Renewable Energy Acceleration Programme (MREAP) which identified two sites for potential wind farms in Mzimba and Rumphi districts by use of WRF Mesoscale Modelling and constraints mapping [26]; installation of wind masts for detailed wind speed measurements at the identified sites was planned for April 2013. The government continued to install small wind turbines to a capacity of 10 kW as part of hybrid systems with solar PV for rural electrification projects.

**Table 3**
Malawi's potential energy from agriculture residues.

| Crop | Annual production (MT) [27,28] | Residue to product ratio (RPR) [29,30] | Residue type [29,30] | Annual crop residues (MT) | Potential heating energy (GJ/annum)[a] |
|---|---|---|---|---|---|
| **Maize** | 3,900,000 | 1.5 | Stalk | 5,850,000 | 90,558 |
| **Tobacco** | 138,000 | 1 | Stalk | 138,000 | 2222 |
| **Coffee** | 1500 | 2.1 | Husk | 3150 | 40 |
| **Rice** | 79,000 | 1.5 | Straw | 118,500 | 1844 |
| **Cassava** | 4,300,000 | 0.2 | Stalk | 860,000 | 15,050 |
| **Cotton** | 32,550 | 3.5 | Straw | 113,925 | 2039 |
| **Total** | **8,451,050** | | | **7,083,575** | **111,752** |

[a] Potential heating energy is calculated using heating values of the crop residues from [29,30,31,32,33,34].

### 5.3. Biomass resource

Malawi typically produces over 7 million tonnes of both crop residues and livestock dung per year. Tables 3 and 4 show estimates of potential energy from crop residues and livestock dung respectively.

Crop residues such as rice husks (shown in Fig. 8) can be compressed into briquettes or pellets for use in improved cook-stoves for heating and cooking. At 15 per cent conversion efficiency for improved cook-stoves [38], crop residues could provide up to 16,762 GJ of energy per annum, while biogas could provide up to 6941 GJ at 30 per cent biogas stove efficiency [39,40]. There is also potential for biogas from municipal solid waste especially from cities where waste collection is significantly high. Potential energy recovery processes from the biomass resources produced in Malawi are shown in Fig. 9.

Malawi also produces a significant quantity of forest residues from forest plantations. The plantations were established in the1960s when it became apparent that the indigenous forest

**Table 4**
Malawi's potential energy from livestock dung.

| Livestock type | Populations [35] | Potential dung production (Tonnes/ annum)[a] | Potential biogas production (1000 $m^3$/ annum)[a] | Potential energy (GJ/annum) |
|---|---|---|---|---|
| **Cattle** | 1,110,560 | 3,242,835 | 74,585 | 1611 |
| **Goats** | 4,442,907 | 1,621,661 | 25,947 | 560 |
| **Sheep** | 228,649 | 83,457 | 1335 | 29 |
| **Pigs** | 2,160,670 | 1,577,289 | 63,092 | 1363 |
| **Chickens** | 44,672,086 | 1,304,425 | 847,876 | 18,314 |
| **Ducks** | 1,014,869 | 29,634 | 19,262 | 416 |
| **Rabbits** | 1,022,864 | 57,280 | 10,649 | 230 |
| **Guinea Fowls** | 1,350,585 | 39,437 | 25,634 | 554 |
| **Turkey** | 145,486 | 4248 | 2761 | 60 |
| **Total** | **56,148,676** | **7,960,267** | **1,071,142** | **23,137** |

[a] Potential dung and biogas production including the potential heating energies were calculated using dung and biogas factors, and heating value of 21.6 MJ for biogas from [36,37].

**Fig. 8.** Rice husks left to decay at a rice milling centre in Karonga, Malawi.

resources would not sustain the local and export need for timber. In total the Malawi Government owns 73,000 ha of timber plantations and about 26,000 $km^2$ of indigenous forest reserves [41,42]. About 68,000 ha of the timber plantations are planted with pine trees, with a few pockets of cypress and cedar tree species; the remaining plantation areas are under eucalyptus aimed at providing fuel wood and poles [41]. Although there is restriction of access into these forest plantations, until recently, dead trees were being collected as firewood free of charge. In areas where forest plantations are being harvested for timber production, forest residues have become a major energy resource with most of it being transported long distances for selling in urban centres. During harvesting of mature stands of trees for timber production, saw millers normally are interested in particular portions of a stand to meet specific requirements. As a result almost one-third of the tree remains in the field as residues when the trees are harvested using efficient equipment [43]. In the Malawi's Viphya plantations, the largest forest plantation in east and southern Africa, covering about 53,000 ha [41]; it is estimated, by the Viphya Plantations management, that 75 to 80 per cent of a tree sawn by small scale sawyers remains in the field. These residues include tops, branches, barks and stumps. Fig. 10 shows a stack of tops from a single tree and Fig. 11 shows a stack of semi round barks loaded for disposal after the logs are extracted in the Viphya Plantations.

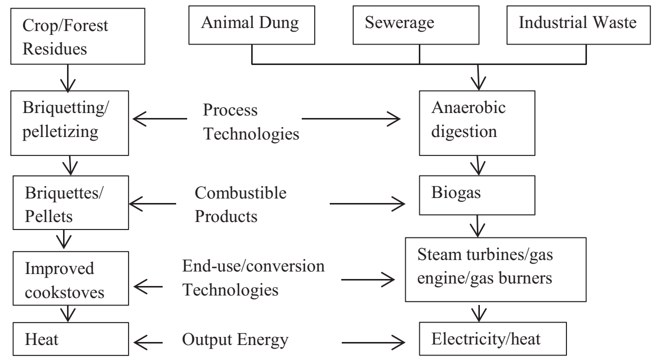


**Fig. 9.** Viable energy conversion routes for Malawi's biomass.

**Fig. 10.** Stack of residues from a single tree after logs have been extracted—Source (Chamayere, unpublished).

Each hectare in the Viphya plantations consists of 1000 stands of pine trees. With the current harvesting practice, a minimum of 6 t of barks are produced per hectare and left on the field as residues [44]. RAIPLY, one of the wood processing companies in Malawi, which has a concession with the Malawi Government for harvesting 20,000 ha of the Viphya Plantations, harvests 200 ha from the concessional area per year. 450 $m^3$ of wood are processed per day from which 225 $m^3$ of wood wastes are generated. In one year RAIPLY generates 61,875 $m^3$ of wood residues. If the forest residues were used to generate electricity, a 3.5 MWe power plant could sustainably be supplied with the residues throughout a year; this figure can be extended up to over 20 years if trees' harvesting is properly matched with replanting taking into account the maturity age of 25–30 years for pine trees. The other residue that is available in large quantities in forest plantations in Malawi but remains under-utilised is saw dust. Saw dust is a potential raw material for production of briquettes and pellets. Yet, saw dust from timber production and primary and secondary wood processing industries is left to decay or just set on fire. At the rate of 450 $m^3$/day of fresh wood being processed into timber, there is untapped potential of producing briquettes from the saw dust which could reduce demand for charcoal and firewood.

Despite the availability of the enormous biomass resource there are challenges to its utilisation. Transportation logistics are difficult due to poor road infrastructure in some of the biomass producing areas, especially during the rainy season. Collection of dung and crop residues is also an issue due, in part, to the free-range system of livestock farming by a significant number of farmers and sparsely distributed smallholder farmers, each farmer

**Fig. 11.** Semi round planks (barks) loaded for disposal—(Chamayere, unpublished).

owning a small number of animals and producing small quantities of crops. Studies in other countries indicate that availability factors of the livestock dung for energy production can range from 0.05 to 0.8 of the total dung produced [37] depending on the type of livestock and the livestock husbandry practices.

One of the successful efforts in biomass energy was the promotion of wood-saving stoves by the Programme for Basic Energy and Conservation (ProBEC), which phased out in 2010. At the time of its phasing out (due to end of project funding), the project had achieved significant adoption and diffusion of the efficient stoves. Over 90 private and community based entrepreneurship groups were trained in production of the efficient stoves through the project [38]. The entrepreneur groups along with other non-governmental organisations continue the production and promotion of the energy efficient stoves for use in households and institutions. Other non-traditional biomass projects include the promotion of biomass briquettes through training of briquette producers by the Government's Promotion for Alternative Energy Sources Project (PAESP); construction of household biogas digesters in Mzimba and Nkhatabay districts by Mzuzu University; and promotion of biogas digesters through the Malawi Renewable Energy Acceleration Programme (MREAP) in Mchinji district.

### 5.4. Hydropower

Malawi has 1.478 GW of unexploited hydropower from rivers spread across the country [45,15]; which is four times the installed capacity of the hydro generation in 2014. Table 5 shows the locations and sizes of potential hydropower sites in the country and projected time frames for development of the sites.

It can be shown from Table 5 that 40 per cent of the unexploited hydro resource is on the Shire River. However, with 98 per cent of Malawi's electricity already generated on the Shire, development of additional hydroelectricity schemes on the river should be justified by detailed risk analysis as one way of ensuring energy security in the country; otherwise sites located on other rivers should be prioritised in future development of hydro generation schemes. Hydro is the most developed renewable energy resource in Malawi.

### 5.5. Geothermal energy

A recent geothermal exploration conducted by Gondwe [8] shows that there are over 50 known hot springs in Malawi with 18 hot springs having an average surface temperature above 50 °C. Some selected hot springs are shown in Table 6.

**Table 5**
Untapped hydropower potential in Malawi [45,46].

| Name of River | Site | Planned Year of Site Development | Electricity Generation Potential (GW) |
|---|---|---|---|
| **Songwe** | Mavolo | 2020 | 0.16 |
| **South Rukuru** | Lower and high Fufu | 2020 | 0.42 |
| **Dwambazi** | Chimgonda | 2040 | 0.05 |
| **Bua** | Chizuma, Chasombo, Malenga, and Mbongozi | 2040 | 0.21 |
| **Shire** | Kholombidzo | 2025 | 0.28 |
| **Shire** | Mpatatmanga | 2035 | 0.3 |
| **Ruo** | Zoa | 2050 | 0.05 |
| **Other** | | – | 0.008 |
| | | **Total** | **1.478** |

**Table 6**
A selection of geothermal sites for Malawi.

| Name | District of location | Average surface-water Temp (°C) |
|---|---|---|
| Mphizi | Rumphi | 82 |
| Chiwi | Nkhotakota | 76 |
| Mtomdoro | Nkata Bay | 72 |
| Mawira 1 | Nkhotakota | 67 |
| Mawira 3 | Nkhotakota | 65 |
| Mawira 4 | Nkhotakota | 64 |
| Chombo | Nkhotakota | 64 |
| Mawira 5 | Nkhotakota | 63 |
| Ling'ona | Nkhotakota | 61 |
| Ngara 1 | Karonga | 59 |
| Ngara 2 | Karonga | 55 |
| July village | Chikwawa | 55 |
| Chipwidzi 1 | Nkhotakota | 54 |
| Mukungwi | Karonga | 52 |
| Mwankenja 2 | Karonga | 51 |
| Mwankenja 1 | Karonga | 50 |
| Mawira 2 | Nkhotakota | 50 |
| Sitima | Balaka | 50 |

From the surface temperature, $T_s$; temperature ($T_z$) of a hot spring at a depth $z$ for a temperature gradient $G$, can be calculated using $T_z = T_s + Gz$ [47,48]. The literature in [49,47,48] recommends generation of electricity from geothermal sites with temperatures above 150 °C using Organic Rankine cycle steam turbines; and extracting heat for industrial processes and/or space heating or cooling using ground heat pumps from sites with temperatures between 40 °C and 150 °C. It can be seen that, even without drilling into the ground, the surface-water temperatures at the sites listed in Table 6 are viable for process and space heating. Based on data from other geothermal sites on the African great rift valley which is where the Malawi hot springs lie; it is predicted that temperature gradients of 100 °C/km could be observed and the geothermal resource for Malawi is estimated at 200 MW [8].

The geothermal resource potential in Malawi has not been exploited; however, a few hot springs are used for supplying hot water to nearby villages for domestic use. In other sites, people use the hot water at the pools directly for bathing and washing clothes. Planning for a 30 MW plant in Nkhotakota started in 2012. It is claimed that the 30 MW plant would be upgraded to 100 MW [8] which is not consistent with the estimated potential of 200 MW from over 50 sites considering that the surface temperature for the planned site is not the highest of the identified geothermal sites. Further measurements and analyses are needed to validate the claims.

Although there is a range of renewable energy resources in Malawi; sustainable development of renewable energy technologies in Malawi is hindered by a number of challenges. These are presented in the next section.

## 6. Challenges for the energy supply industry in Malawi

Challenges affecting the energy supply industry of Malawi include but one not limited to increasing energy-demand, lack of finance for large scale energy projects, shortage of trained human resource, poor governance, weak legislation and weak regulatory framework. The challenges are discussed as follows.

### 6.1. Increasing energy-demand

In view of the low energy per capita consumption and accounting for the positive correlation between electricity and energy consumption with GDP [50,51] it is clear that growing the economy and improving living standards in Malawi will result in increased energy demand. For example, the minimum electricity demand to meet the total population's household energy services alone is estimated at 700 MW [15]. Based on the 2008 census, there were about 2,870,000 households. It is likely that if all households were connected to the grid and had enough income to purchase basic electrical appliances such as refrigerators, cookers, and TV; the peak electricity demand by households alone could be over 3 GW. The Malawi government also estimates that the minimum electricity energy demand for irrigation agriculture under the planned green belt initiative is 130 MW whereas the electricity demands for the booming mining sector; heath, education, banking, ICT services and offices; and manufacturing and processing; are estimated at 800 MW, 500 MW, and 700 MW respectively [15] which totals to 2830 MW. Fig. 12 shows electricity demand-growth projections by the Department of Energy Affairs.

The projections shown in Fig. 12 are likely to have been underestimated considering Malawi's low access to electricity which has remained at 8 per cent since 2010; load shedding carried out by the country's electricity utility company; people's tendency to buy and use more electrical appliances when they have access to electricity; and the unmet electricity demand of industries operating off-grid using independent diesel generators because of the country's low electricity generation capacity. If the transmission and distribution network were accessible to every household, capital costs for connection to the grid were affordable to the majority of households, and the installed capacity of electricity generation were adequate, the demand projections would show a high growth-rate at the beginning slowing down with time as households reach saturation of household electrical appliances and industrialisation fully realised, leaving population growth rate as the only major factor dictating energy demand. With the country's population growing, estimated at 15.91 million in 2013 from 13 million in 2008, it also means that the demand for firewood for cooking and many other energy services is growing significantly and thus adds pressure to the limited energy infrastructure and resources.

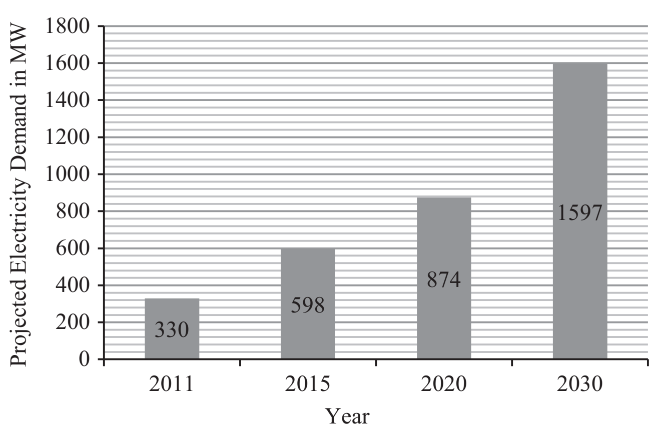


**Fig. 12.** Malawi's electricity demand projection – (2011 value is actual) data source [15, 69].

### 6.2. Financing

Malawi's weak economy constrains the financing of large scale energy projects. Even small scale energy projects suffer from uncertainties of financing for operation and maintenance costs. Small and medium scale projects are funded from fuel levies which are in turn constrained by the low fossil fuel per capita consumption due to limited number of vehicles and limited industrial activities in the country. So most of the large-scale projects depend on financing from multilateral organisations and donations from external governments; this is not sustainable considering the global economic crisis affecting potential development partners to Malawi. Sometimes, it also occurs that external funding has many conditions attached, particularly on governance and human rights issues, some of which conflict with the social and cultural heritage of Malawi, raising fears on the sustainability of funding from international development partners especially if Malawi decides to defend its position on social and cultural heritage. For example, there have been cases where external governments have frozen funding for projects because of Malawi's position on certain minority rights criticised by the majority of Malawians as not being representative of the culture of Malawi, but the concerned development partners argued that the actual reason was poor governance and they claimed that the Malawi Government was misinforming its citizens. In the Government's Barrier Removal to Renewable Energy Projects funded by the Global Environment Facility (GEF), one of the objectives that were not fully addressed was the identification of viable financing mechanisms for renewable energy technologies; and this continues to be a challenge for the adoption and diffusion of renewable energy technologies in Malawi.

### 6.3. Human resource and training

Malawi has a limited number of trained personnel for development, implementation, operation and maintenance of large scale energy systems. Large scale energy projects are usually contracted to external companies. The situation is complex in the delivery of renewable energy technologies which are relatively new. Although energy programmes are offered in vocational and higher education institutions, the education institutions are incapacitated in research and laboratory equipment thus affecting the quality of technical training delivered. For example, the lack of local technical expertise is cited as one of the reason that resulted in 50 per cent of the 5000 Solar Home Systems installed since 2000 becoming non-operative by 2003 [13]. This is also evidenced by the importation of human resource during development and maintenance of major energy systems in the country; and sometimes system components are sent to other countries for maintenance. The financial implications associated with logistics of sourcing trained human resource from other countries to install and/or maintain renewable energy systems in Malawi; for example, for commercial wind farms, is potentially over MK36,000,00.00 ( £60,000.00) annually per MW of installed capacity [26]. And as a result of the weak economy, there is high likelihood of renewable energy systems being affected by delayed maintenance

leading to lower capacity factors or performance ratios thereby reducing the lifecycle benefits of the systems.

### 6.4. Regulation and governance

The Malawi Energy Regulatory Authority (MERA) is mandated to regulate the energy sector [52] using the Energy Laws as the major legal instrument; while the Malawi Bureau of Standards (MBS) enforces adherence to standards for, but not limited to, energy systems installation. However, independence of the bodies is not clear especially during implementation of projects led by government and when enforcing policies that may affect political alignments of people. There is high likelihood that systems can be hastily certified and commissioned to register political milestones while compromising on quality or sustainability criteria. Other conflicts arise between policies of different government sectors because of lack of coordination. For example, the agriculture sector would tolerate cultivation along the river banks as one way of supplementing rain-fed agriculture to enhance food security, but this could disadvantage energy generation because of resultant siltation in rivers that consequently affects turbines downstream: The Electricity Supply Corporation of Malawi shuts down its turbines every year to de-silt its dam; part of the siltation could be as a result of unregulated and/or unmonitored cultivation along the river banks.

In view of the situation presented above, a PESTLE analysis is discussed in the next section in order to provide a comprehensive framework for addressing the sustainability challenges facing the Malawi energy sector.

## 7. A PESTLE approach for developing renewable energy systems in Malawi

Unlike the SWOT analysis [53], which identify issues in generalised categories of strengths, weaknesses, opportunities and threats, a PESTLE analysis classifies issues as political (P) economic (E), social (S), Technological (T), legal (L) and environmental (E) [53]. In context to this paper, the PESTLE criteria is focussed on issues which policy makers and developers should address in order to ensure sustainable diffusion and adoption of renewable energy solutions which can help communities to achieve sustainable livelihoods and the millennium development goals.

### 7.1. Political

Apart from the political interference mentioned in section 6; most recently, it has been observed that politicians distribute renewable energy technologies for free to households probably for campaigning reasons. Whilst this practice can lead to improved adoption and diffusion of renewable energy technologies, it should be noted that philanthropic financing of renewable energy systems exacerbates sustainability challenges by creating beneficially dependence on donations and by reducing sense of systems ownership [54]. Also, the approach fails to provide a long-term solution to the challenge of high capital costs of the technologies; some beneficiaries would not be able to purchase the systems at the end of the life of the free systems and thus the benefits of the technology could be temporary. Perhaps the funds used for the free distribution of the technologies could be used for setting up local renewable-energy-technology subsidy programmes which could probably result in increased number of beneficiaries and enhanced ownership of systems.

### 7.2. Economic

High capital costs along with higher levelised cost of energy present a significant barrier to the promotion of renewable energy technologies. In 2013, Zalengera [55] found out that household willingness to pay for capital costs at Likoma Island averaged US$90.00 and the monthly household willingness to pay for energy, US$6.00, was half of the prevailing energy costs. Given Malawi's economic overview presented in section 1; it is likely that this could be the prevailing economic conditions for the majority of households in the country. Based on the minimum energy requirement, an average household of 5 in Malawi [3] would need 300 kWh per month [56]. In order to meet this energy requirement from electricity, a household would need a system rated at least 1.7 kW with a capacity factor of at least 25 per cent and with storage. Such a system would initially cost over US$3000.00; whereas grid-based renewable generated electricity would result in a monthly energy expenditure of USS$21.00 at the subsidised electricity tariff of March 2014. Moreover, household grid connection is charged at US$80.00 and wiring of an average house would cost at least US$500.00. On the other hand, a commercially available solar water heater costs at least US $500.00. A 4 $m^3$ biogas digester to meet the average household cooking energy requirement would require a capital cost of at least US$1000.00. Solar cookers would cost less than the household willingness-to-pay for capital costs but their usage would be limited due the social issues discussed in section 7.3. Thus, without innovative financing mechanisms and feasible business models; the adoption of renewable energy technologies will remain low. The rural electrification fund which was established for financing energy initiatives for rural areas is used to support investments by companies. Likewise, the feed-in tariff policy set the minimum eligible size at 500 kW which can only be implemented by rich companies. In both cases the financing could be extended to households and institutions. Since the rural electrification fund is prioritised for projects which can contribute at least 20 per cent of the capital costs for the energy investment, the fund could be used to finance households and /or institutions to install grid connected renewable energy systems in the range of 1–5 kW and with net-metering. The financed households or institutions would be able to repay part or whole of the capital costs from the feed in tariff. It should be noted that household would even be paid for energy which would be generated for their own use as it is similar to feeding renewable generated energy into the grid. Apart from addressing the energy poverty and energy security problems, the arrangement would also address the prevailing household financial poverty rather than the current arrangement which directly benefits only rich entrepreneurs and a few individuals who would be on permanent employment. In view that other schools of thought would advocate for cheap systems which are claimed to be affordable by low-income households; it should be noted that such market-based approaches only exacerbates the sustainability challenges arising from compromised quality assurance and short lifespans. A sustainable dissemination of renewable energy systems cannot be achieved by increasing affordability through development of cheaper products but by fostering income-generating activities (and financing mechanisms), which facilitate paying for good quality systems capable to meet people's energy need [57]. Zalengera et al [58] also found out that the solar and wind feed-in tariffs that were introduced in 2012 are lower than empirically modelled levelised cost of energy for the technologies. Thus, an early review of the tariffs is required; otherwise private entrepreneurs would not invest in the renewable energy generation or there would be a proliferation of poor quality systems which would lead to poor performance thereby tarnishing the image of the technology.

### 7.3. Social

Technologies and their development methodologies including financing mechanisms should be adapted to contexts in which they would operate. This requires in-depth knowledge of a number of aspects such as energy needs and requirements; prioritisation of energy services; purchasing power; satisfaction of energy services and experiences with prevailing energy technologies; social practices and social set-up of communities; and available technical skills. Alam et al. [59] reported experiences from Bangladesh where households rejected family-size solar cookers in preference to large solar cookers for communal kitchens. Similarly, Hong & Abe [60] observed that lack of post-installation support by a community for an isolated PV mini-grid in Philippines, was in one part, caused by misalignment between the project objective and the community priorities. The system was installed for lighting which was second to food and cooking on the priority listing for the community. Zalengera [61] reported a biogas-digester failure due to erratic feeding: the norm of the household was that only the household leader (male) could collect dung from the cattle pens; thus whenever the household leader was not home for a considerable number of days the digester could not be fed. Furthermore, it should be noted that certain technologies such as biogas, if not appropriately designed, can be labour intensive i.e. feed collection, mixing of influent slurry, and fetching water (if no water point is available nearby). The labour demand can lead to abandonment of technologies if traditional energy sources such as firewood are relatively more convenient and less involving than the new technologies. Sometimes, the type of the staple food for communities also determines the social acceptability of technologies. For example, as Owen et al. [16] observed, solar cookers are not appropriate for food and cooking habits of Malawi. Both the box type and parabolic dish solar cookers would be appropriate for foods such as potatoes and rice, and boiling water whereas the staple food is Nsima which involves continuous physical handling of a pot. To a certain extent, the parabolic type solar cooker shown in Fig. 13 can be used for Nsima preparation.

However, as shown in Fig. 13, the solar cooker requires that it has a large surface area to yield enough energy but allowing comfortable access to the pot at the focal point by the user; and should have mechanical strength to stand the cyclic loads associated with Nsima preparation. In addition, minimising the shade from the user as well as reducing the discomfort of the user for having to cook in the open and be subjected to the sun present more challenges.

Catering services and customs associated with communal events such as wedding and funeral ceremonies present additional challenges relating the energy requirements of communities and design of end-use technologies. These are areas which need more research to determine the flexibility of cultures and any features that would need to be integrated in the design of renewable energy technologies. A report by UNESCO [62] agrees that truly lasting development has a cultural basis.

Rogers [63] summarises the above observations in his theory of diffusion which states that diffusion of innovation is driven by (a) relative advantages between the available choices measured in economic, social prestige, convenience and satisfaction; and (b) compatibility of available technology choices with existing values, past experiences and needs.

### 7.4. Technology

Oftentimes technology selection of renewable energy systems is based on subjective choices limited by the knowledge of developers or practitioners and thus all available options are not considered. The bias for certain technologies also determine the output-energy that is promoted i.e. whether electricity, heat, or mechanical power. Studies, for example in [50], showing correlation between electricity consumption and quality of living, create a bias towards electricity. Although electricity is considered fundamental for modern living it may not the appropriate form of energy for every energy need [64] and could be inefficient for meeting certain energy needs like cooking and heating. For example, with a PV array efficiency of 15 per cent and a cooker efficiency of 68 per cent [16]; the overall efficiency becomes 8% whilst solar thermal systems have efficiency above 30 per cent. At least 50 per cent of per capita energy consumption is for heating and cooking. Meeting the cooking and heating energy requirements from electricity would increase the capital costs of energy systems. The obsession for electricity is observed in the rural electrification act and the feed-in tariff policy where there is no specific citation of technologies for direct heating despite their significant potential to offset energy demand from the overloaded grid. With firewood becoming scarcer, renewable energy technologies for cooking and heating such as solar cookers and solar water heaters, biomass briquettes, and biogas could be more important than small scale solar PV and /or wind energy technologies designed only for lighting particularly for households. Moreover, due to capital costs for electric cooking appliances, provision of electricity does not automatically lead to a shift from traditional or conventional cooking technologies. Furthermore, the obsession for electricity has shifted the attention by stakeholders from mechanical wind systems which would be appropriate for the low wind speeds experienced in the country. The mechanical water pumps would be suitable for community water supply and irrigation agriculture during the summer dry season when the relatively high wind speeds coincide with water scarcity due to low water table. There is also potential for mechanical wind mills being locally produced and such systems have already been demonstrated but lack market promotion.

Similarly, for geothermal resource which can be used for heat or electricity production, developers would need to consider the following factors.

(i) The flexibility of transporting the produced energy to load centres: Electricity can easily be transported over long


**Fig. 13.** Typical design of parabolic dish solar cooker produced in Malawi—adapted from http://solarcooking.wikia.com/wiki/Malawi.

distances compared to heat which presents challenges at distances longer than 30 km [47]. Although some geothermal sites are near to households, industries where process heating could be important are located hundreds of kilometres away from the potential geothermal sites.

(ii) Efficiency and capacity factors: Organic Rankine Cycle (ORC) turbines used for geothermal electricity generation typically operate with efficiencies ranging from 10per cent to 17 per cent [48] whereas ground source heat pumps operate with efficiencies, usually termed as Coefficient of Performance, COP, ranging from 300 per cent to 600 per cent [3] [49]. However, efficiency has to be considered together with capacity factor noting that geothermal heat pumps require electricity or fuel-driven engines to operate, thus their capacity factor may be affected by the availability of the primary energy driving them. On the other hand, capacity factors of over 90 per cent have been reported for geothermal plants generating electricity if the correct temperatures available [47].

In order to avoid technology-centeredness when promoting renewable energy technologies, the criteria for selecting appropriate sustainable technology by Dunmade [65] would be useful viz: simplicity; affordability and financial viability; ability to guarantee comfortable life; save human energy and time; ability to increase income; ease of maintenance and time between repairs; ease of transfer of knowledge and skills; availability of local champion to continue after implementation[4]; capacity to meet needs; social equitability; cultural acceptability; supply of materials and spare parts; resource consumption e.g. water and other materials; and environmental benefit. The criteria could be weighted.

### 7.5. Legal

The duty and surtax waiver on importation of renewable energy technology equipment helps to reduce capital costs. This enhances affordability of renewable energy systems which can lead to improved adoption and diffusion; However, legal instruments are required to address the potential -abuse of tax waiver by retailers: Surveys carried out in some parts of Malawi show that the tax waiver on importation of renewable energy technologies is not reflected in the retail prices; consequently, renewable energy technologies remain at prohibitive prices. Second, importation and implementation of substandard systems, which damages the reputation of renewable energy technologies in the country requires clear regulation enforcement. There have been cases of systems; particularly battery based solar PV systems, becoming non-operative within one year of implementation. This is, in one part, as a result of lack of independent quality checks on the imported system components due to unavailability of testing centres for renewable energy technologies in the country. A testing centre (TCRET) was established at Mzuzu University in 2003 but it is not operational yet. Lack of independent quality checks before commissioning of renewable energy systems also contribute to the implementation of substandard systems. A clear legal framework is required to regulate a transparent coordination among Malawi Revenue Authority which takes control of importation, Malawi Bureau of Standards, TCRET, renewable energy consultants, and contractors. Third, deliberate policies could be formulated; for example, obliging institutions such as boarding secondary schools and prisons to source part of their energy for cooking and water heating from biogas digesters[5] or from solar thermal systems thereby reducing the demand for firewood and/or electricity for cooking by secondary schools and other facilities. Similar policies have been key drivers of renewable energy technologies in Western countries whereby energy suppliers are obliged to source part of their energy from renewables. Fourth, wherever possible, imported systems could be avoided: It would be cost effective to use simple systems produced by local companies which makes it easy to source local maintenance expertise and spares when systems fail. For example, despite the availability of companies that locally manufactured solar water heaters, intuitions including government had continued to install imported solar water heaters leading to the collapse of the local manufacturing which would have been contributing to the economic growth of the country through creation of direct employment and indirect employment in the associated supply chain industry. A deliberate policy framework encouraging potential adopters of renewable energy technologies to procure local systems where possible would improve the current practice whereby there is a tendency of people having more trust in imported systems than local systems.

### 7.6. Environmental

The need for the mitigation against climate change can make some developers restrict environmental concerns to emissions. Although renewable energy technologies have potential to reduce emissions, their implementation can have local environmental impacts. For example effluent from biogas digesters; particulates from biomass combustion; noise and interference with communication systems from wind turbines [66]; and landscape changes can cause negative effects on the local environment. Therefore consideration should be given to full environmental impact assessment and appropriate environmental management systems should be designed for the potential impacts. Furthermore, although some financers place emphasis on carbon emission savings when funding energy technologies, government and/or local institutions should be able to weight appropriately the criteria for identifying an energy technology based on local definition of sustainability and sustainable livelihoods of communities: sustainability is founded upon the concept of sustainable development, defined as "*development that meets the needs of current generations without compromising the ability of future generations to meet their own needs* [67]"; whilst sustainable livelihoods is defined *as "a livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks; maintain or enhance its capabilities and assets, while not undermining the natural resource base*" [68]. From the two definitions there is a risk, especially for developing countries, of one placing more emphasis on the meaning of *"without compromising the ability of future generations to meet their own needs"* and the meaning of "*while not undermining the natural resource base*" respectively without weighting appropriately the scope and contextual definition of *"meeting current needs"* and *"enhancement of people's capabilities and assets"* considering the leapfrog of energy infrastructure required for poor communities.

[3] It means for every unit of energy that drives the pump, the output is 3–6 times; for example, 100 kWh from electricity driving the heat pump would deliver between 300–600 kWh of heat from the ground heat source.

[4] It would require planning personnel training in advance of installation and not after installation when system faults have started showing up.

[5] Human waste and food waste could be a potential feedstock. Phwezi secondary school is a good example of an institution using biogas produced from human waste.

## 8. Conclusion

In this paper, the energy situation of Malawi has been outlined and data of renewable energy resources for Malawi including advances of renewable energy technologies up to 2014 are presented. The challenges for the country's energy sector are discussed and a PESTLE framework for delivery of renewable energy technologies has been laid out. It is shown that further to the energy balance leaning towards traditional biomass, the energy supply in Malawi is inadequate and unreliable. However, the data presented show that Malawi is endowed with renewable energy resources which could enhance the energy security for the country. Solar, non-traditional biomass and hydropower are the most certain renewable energy resources that can contribute significantly to the energy supply of the country. There is optimism for wind and geothermal; but further work to determine the ground temperatures of the Malawi hot springs, and collection of wind data at heights of at least 10 m above the ground is required for comprehensive determination of geothermal and wind resources. It is also observed that although the Malawi National Energy Policy clearly lays out the steps towards improving the country's energy situation; unreliable financing mechanisms for large scale energy projects, shortage of trained human resource, lack of coordination among local institutions; unclear regulation framework and sometimes political governance impede the sustainable execution of energy projects. The PESTLE analysis included in the paper provides a novel thinking for addressing the political (P), economic (E), social (S), technological (T), legal (L), and environmental (E) challenges affecting the sustainability of renewable energy technologies in Malawi. The analysis suggests a paradigm shift that has potential to provide long-term supporting mechanisms for Malawi's renewable energy development. It is evident from the paper that holistic approaches are crucial for strengthening Malawi's energy sector, and it requires radical political and governance decisions.

## References


[1] Malawi Government. The Warm Heart of Africa; 2011. [Online]. Available: 〈http://www.malawi.gov.mw/〉 [accessed 8.11.11].
[2] World Bank. World development indicators–Malawi; 2013. [Online]. Available: 〈http://data.worldbank.org/country/malawi〉 [accessed 21.05.13].
[3] National Statistics Office of Malawi. Malawi census main report, National statistics office. Zomba; 2008.
[4] Millennium challenge account-Malawi. Concept paper for the energy sector. Malawi government, Lilongwe; 2011.
[5] Trading economics. Malawi economic Forecasts; 12 March 2014. [Online]. Available: 〈http://www.tradingeconomics.com/malawi/forecast〉 [accessed 12.03.14 ].
[6] World Bank, Malawi Country Brief; 2010. [Online]. Available: 〈http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/MALAWIEXT/0,,print:Y~isCURL:Y~menuPK:355882~pagePK:141132~piPK:141107~theSitePK:355870,00.htm〉 [accessed 10.10.11].
[7] Ministry of development and planning cooperation. 2010 Malawi Millennium Development Goals Report. Malawi Government, Lilongwe; 2011.
[8] Gondwe K, Allen A, Georgsson L, Loga U, Tsokonombwe G. Geothermal development in Malawi- a country update. Paper presented at the 4th African rift geothermal conference. Geothermal solutions to Africa's energy needs, UN Gigiri complex,Nairobi, Kenya, Nairobi; 21–23 November 2012.
[9] Kaunda S. Energy situation, potentail and application status of small-scale hydropower systems in Malawi. Renew Sustain Energy Rev 2013;26:1–19.
[10] Gamula G, Hui L, Peng W. Development of Renewable Energy Technologies in Malawi. International Journal of Renewable Energy Technology Research 2013;2:44–52.
[11] Tenthani C, Kaonga C, Kosamu I. The potential of distributed generation in Malawi. Int J Renew Energy Res 2013;2(1):29–32.
[12] Electricity Supply Corporation of Malawi. Generation capacity; 2011. [Online]. Available: 〈http://www.escom.mw/power_generation.php〉 [accessed 8.10.11].
[13] Ministry of Energy and Mining. National Energy Policy for Malawi. Lilongwe: Malawi Government; 2003.
[14] COMESA. Baseline renewable energy database for the COMESA Region. COMESA, Lusaka, Zambia; 2012.
[15] Lapukeni P. Country report-status of energy policy in Malawi-presented at the Japanese International Cooperation Agency Centre in Tokyo; 2013. [Online]. Available: 〈http://eneken.ieej.or.jp/data/5006.pdf〉 [accessed 11.03.13].
[16] Owen M, Openshaw K, Van der Plas R, Matly M, Hankins M. Malawi biomass energy strategy. Lilongwe: Malawi Government; 2009.
[17] Kambewa P, Chiwaula L. Biomass energy use in Malawi. A background paper prepared for the International Institute for Environment and Development (IIED) for an International ESPA Workshop on Biomass Energy. Parliament House Hotel, Edinburgh. Zomba: Chancellor College; 2010.
[18] Department of Energy Affairs. Promotion of alternative energy sources project document. Lilongwe: Ministry of natural resources, Energy and mining; 2006.
[19] Ezekwesili O, Godron O, Ghir Jea. Project appraisal document for a proposed grant and a proposed credit to the republic of malawi for the energy sector support project. Lilongwe: World Bank; 2011.
[20] Brown D. Uranium Mining in Malawi. [Online]. Available: 〈http://uraniuminvestingnews.com/8029/uranium-mining-in-malawi.htm〉 [accessed 31.01.12].
[21] Malawi Government. Vision 2020; 2011. [Online]. Available: www.sdnp.org.mw [accessed 10.10.11].
[22] Malawi energy regulatory authority. Malawi feed-in tarrif policy—renewable energy resource generated electricity in Malawi, Lilongwe: Malawi Energy Regulatory Authority; 2012.
[23] Department of climate change and meteorological services. Chichiri solar radiation data; 2010.
[24] Duffie J, Beckman W. Solar thermal engineering processes. New Jersey: Wiley; 1991.
[25] Ministry of development planning and coorperaton. Annual economic report, Malawi Government, Lilongwe; 2011.
[26] Sgurr energy. Inititial feasibility study and nationwide sonstraints mapping. Malawi Renewable Energy Acceleration Programme, Glasgow; 2013.
[27] FAO. Food Outlook Global Market Analysis; 2011. [Online]. Available: 〈http://www.fao.org/docrep/014/a1981e/a1981e00.pdf〉 [accessed 20.01.12].
[28] US department of agriculture. Malawi agriculture production Statistics; 2011. [Online]. Available: 〈http://www.indexmundi.com/agriculture/?country=mw&commodity=corn&graph=production〉 [accessed 20.01.12].
[29] Duku M, Gu S, Hagan E. A comprehensive review of biomass resources and biofuels potentail in Ghana. Renew Sustain Energy Rev 2011;15(1):404–15.
[30] Eisentraut A. Sustainable production of second-generation biofuels. Potential and perspectives in major economies and developing countries IEA. Paris.
[31] Kumar A, Purohit P, Rana S, Kandpal T. An approach to the estimation of the value of agriculture residues used as biofuels. Biomass Bioenergy 2002;22(3):195–203.
[32] Saenger M, Hartge E, Werther J, Ogada T, Siagi Z. Combustion of Coffee Husks. Renew Energy 2001;23(1):103–21.
[33] Zabaniotou A, Ioannidou O. Evaluation of utilisation of corn stalks for energy and carbon material production using rapid pyrolisis at high temeprature. Fuel 2008;87(6):834–43.
[34] Acaroğlu M, Aydoğan H. Biofuels Energy Sources and Future of Biofuels Energy in Turkey. Biomass Bioenergy 2012;36(0):69–76.
[35] Livestock in Malawi; 2011. [Online]. Available: 〈http://livestockinmalawi.page.tl/Facts-and-figures.htm〉. [accessed 25.01.12].
[36] Arthur R, Baidoo M, Antwi E. Biogas as a potential renewable energy source: a Ghanaian case study. Renew Energy 2011;36(5):1510–6.
[37] Batzias F, Sidiras D, Spyrou E. Evaluating livestock manures for biogas production: a GIS based method. Renew Energy 2005;30(8):1161–76.
[38] ProBEC. Saving energy for the future-countries; 2007. [Online]. Available: 〈http://www.probec.org/displaysection.php?czacc=&zSelectedSectionID=sec1192750452〉 [accessed 17.07.12].
[39] Itodo I, Agyo G, Yusuf Y. Performance Evaluation of a Biogas Stove for Cooking in Nigeria. J Energy South Africa 2007;18(3):14–8.
[40] Khandelwal K, Gupta V. Popular summary of the test reports on biogas stoves and lamps prepared by testing institutes in China, India and the Netherlands. Netherlands: SNV; 2009.
[41] Luhanga J. The timber trade in Malawi. Southern Afrca resource Watch; 2009.
[42] Department of forestry. In: Juma A.M. (editor). Pondering over our energy future -issues and options in the Malawi Energy Sector in Society of Malawi: Mzuzu; 2006.
[43] Sims R. The brilliance of bioenergy—in business and in practice. First ed.. William Road, London: James & James (Science Publishers) Ltd; 2002.
[44] Chamayere G. Analysis of sustainability of supply of forest residues for installation of power plant in Chikangawa Forest (unpublished). Mzuzu: Mzuzu University; 2009.
[45] Gondwe M. Impacts on generation. The case of Malawi's run-of river hydro power schemes. In: Proceedings of the Conference attendance report for the 6th International conference on hydropower: hydropower supporting other renewables. Blantyre: ESCOM; 2010.
[46] Malawi Government. Concept paper for the energy sector—public private partnerships for electricity generation for rural areas (2011–2016). Millennium Challenge Account: Lilongwe; 2011.
[47] Twidell J, Weir T. "Geothermal energy" in renewable energy resources. Second ed.. London and New York: Taylor & Francis; 2006; 471–88.
[48] Kose R. Research on the generation of electricity from the geothermal resources in simav region, Turkey. Renewable Energy. Renew Energy 2005;30(1):67–79.
[49] Self S, Reddy B, Rosen M. Geothermal heat pump systems: status review and comparison with other heating options. Appl Energy 2013;101:341–8.

[50] Jumbe C. Cointegration and cuasality between electricty and GDP: emperical evidence from Malawi. Energy Econ 2004;26:61–8.
[51] Samoilidis J, Mitrolopulos C. Energy and economic growth in industrialized countries. Energy Econ 1984;6:191–206.
[52] Malawi energy regulatory authority. MERA Mandates. [Online]. Available: 〈http://www.meramalawi.mw/mera/?q=content/mera-mandates〉. [accessed 12.10.11 ].
[53] Basu R. Tools for analysis—PESTLE analysis in implementing quality: a practical guide to tools and techniques. Fisrt ed.. London: Thomson Learning; 2004; 98–100.
[54] Zalengera C. Role of renewable energy for sustainable livelihoods: a case study for developing countries, Malawi in particular. Loughbrough: Loughborough University; 2010.
[55] Zalengera C, Blanchard R, Eames P. Understanding people's purchasing-power for energy: how important is it for sustainable development of renewable energy systems—the case of Likoma Island. London: 3rd low carbon energy development network workshop, 24–25 June 2013, 1–24 June 2013: Wellcome Trust; 2013.
[56] Practical action in D. Tennakoon. Energy poverty: Estimating the level of energy poverty in Sri Lanka. Practical action; 2008.
[57] Lindner K. Quality issues in the market based dissemination of solar home systems in micro perspectives for decentralised energy supply. Berlin: Technische Universität Berlin; 2011.
[58] Zalengera C, Blanchard R, Eames P. Investigating the feasibility of solar photovoltaic and wind electricity integration for Likoma Island in Malawi: techno-economic analysis applying the hybrid optimization model for electric renewables (HOMER). In renewable energy in the service for mankind, London; 3–8 August 2014. (in press).
[59] Alam HM, Kamp L, Pachova N. Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh—an innovation system analysis. Energy Policy 2010;38(8):4626–34.
[60] Hong G, Abe N. Sustainability assessment of renewable energy projects for off-grid rural electrification: the Pangan-an island case in the Philippines. Renew Sustain Energy Rev 2012;16(1):54–64.
[61] Zalengera C, Blanchard R, Eames P. Sustainable livelihood approach to renewable energy technology development–experiences from Malawi. Presented at the 2012 Tech4Dev. Technologies for sustainable development: a way to reduce poverty? EPFL, Lausanne, Switzerland; 2012.
[62] UNESCO. Our Creative Diversity; 1995. [Online]. Available: 〈http://www.powerofculture.nl/uk/archive/report/intro.html〉. [accessed 10.01.12].
[63] Rogers EM. Diffusion of innovations. New York: Free Press; 1995.
[64] DFID. Energy for the poor-underpinning the millennium development goals. DFID: London; 2002.
[65] Dunmade I. Indicators of sustainability: assessing the suitability of a foreign technology for a developing economy. Technol Soc 2002;24:461–71.
[66] Twidell J, Weir T. "Wind Power," in renewable energy resources. Second ed.. London and New York: Taylor & Francis; 2006.
[67] United Nations. Our common future. United Nations; 1987.
[68] Scoones I. Sustainable rural livelihoods. A framework for analysis. Institute of development studies: Brighton; 1998.
[69] Department of Energy Affairs, Project Proposal on Wind Power Generation in Malawi, Malawi Government, Lilongwe, 2011.